Frost as a Cause of Disease in Trees

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FROST AS A CAUSE OF DISEASE IN TREES.

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Introduction.

It has long been a habit to ascribe to frost much disease involving die-back of shoots or death of leaves. The extent to which frost is a real cause of disease has, however, never been fully decided and it is still often a matter of opinion whether in a particular case frost is the real cause of trouble or not. These differences of opinion are partly due to the difficulty of deciding exactly what is and what is not frost damage, and partly to lack of general information on the subject. In this short paper it is impossible to describe in detail all the various ways in which frost may injure trees. All that can be done is to mention those likely to be of most importance and especially some types of damage that have been very frequent since the spring of 1927 on trees important in British forestry. It should be realised that frost can be and often is a very important cause of loss either in the nursery or the forest. Exactly how important in British forestry frost damage is cannot be stated, but it is more often the first cause of disease than is sometimes recognised.

Seasonal Occurrence.

Frost is usually referred to by the season in which it occurs. Thus there is winter frost, spring or late frost, and autumn or early frost. Frosts occurring during the winter, when none of the important forest tress are active

or growing, do not cause serious damage as a rule and will not be further discussed. Nearly all frost damage takes place during the growing season and is due either to late or early frosts. In Britain by far the greater amount of damage is due to late frosts, but in some seasons trees that ripen their shoots late may suffer severely by early frost.

Types of Frost Damage.

Frost damage differs in tpye according to the part of the tree injured, and this depends largely on the stage of development of the tree at the time the frost occurs. The different principal types of damage may be set out in order as follows :—

Damage by Late Frost.

(*a*) *Before shoot development.*

(1) Reddening of the leaves of conifers.

(2) Injury to the cambium.

(*b*) *After shoot development.*

(1) Injury to the cambium.

(2) Death or injury of new shoots and leaves.

(3) Injury to the bark.

Damage by Early Frost.

(1) Death of tips of unripened and, especially, lammas shoots.

(2) Injury to the cambium.

It may be taken that any living part of a tree is liable to damage by frost but that those parts in which growth is most active are the most susceptible. Thus the cambium, which is active throughout the growing season is always liable to injury; but since growth in general is most actively taking place in the spring, it is at this season that the most frost damage occurs.

Reddening of the Leaves of Conifers.

This type of damage is liable to occur in any of the evergreen conifers important in British forestry. It has been most commented on by continental authors and was investigated experimentally by Neger (5). The leaves affected turn reddish in colour and then drop off. Neger showed on Norway spruce that this is due to frost occurring when growth is just starting and assimilation becoming active. The leaves on the last year's shoots are the most susceptible and often the only ones to be affected. He attributed this to their being the first to become actively assimilating. The red colour is not due to the frost but develops after the leaves have been injured and only in the light.

Injury to the Cambium.

This is one of the most important forms of frost damage. The cambium in our important forest trees will withstand severe cold when in a resting condition, but immediately it becomes active it is liable to injury by frost both in broad-leaved trees and conifers. Only in the latter, however, is this type of injury of any real importance. The degree of damage caused depends on the intensity of the frost and the susceptibility of the species to it. The cambium may be killed outright or so injured that it cannot successfully recover; or with less severe cold it may be merely stimulated to make abnormal growth. The result of the abnormal growth is most easily seen in the wood. In conifers, instead of tracheids a parenchymatous tissue develops and the medullary ray cells become enlarged and distorted. The zone of tissue thus formed is known as a frost ring. Abnormal growth also takes place in the phloem, but its result is much more difficult to trace.

Although frost rings are most commonly found in conifers, they also occur among broad-leaved trees and shrubs, e.g., after the late frost at the end of April, 1927, frost rings and cankers occurred commonly on rhododendron stems. In general, however, it may be said that none of our important broad-leaved trees are in any way liable to be seriously damaged by the frosting of the cambium. Conifers vary greatly in their liability to develop frost rings, i.e.,

in the susceptibility of the cambium to frost. The most susceptible are the N.W. American species, Douglas fir, Sitka spruce, Thuja plicata and Lawson's cypress. Japanese larch is almost if not equally as susceptible as these, but in European larch it is unusual to find broad frost rings. When in a Japanese larch or Douglas fir a part of the cambium is killed, a broad frost ring always develops from that remaining alive, but in an European larch so injured only a very narrow frost ring would be found. Frost rings are not infrequently to be found in other conifers; indeed, they may always be looked for in trees growing in localities subject to severe frosts.

The importance of frost ring development is not in itself very great, and any ill-effect suffered by the tree is at the most only temporary. Serious damage arises only when the cambium is killed. Then a frost canker develops, or if the whole circumference of the cambium is affected the stem or branch is girdled and, of course, dies. The cankering or girdling of the tree by frost results in several types of damage :—

(1) The girdling of the main stem near to the ground.

(2) The die-back of the leading shoots of the side-branches or main stem.

(3) The formation of cankers on the main stem or side-branches.

The Girdling of the Main Stem near the Ground.

This is the most serious form of frost injury to the cambium, since it results in the loss of the whole tree. So far it has been observed as occurring to a serious extent only in Douglas fir and Sitka spruce. In certain localities both these species suffer severely from this type of damage. The cambium becomes active before the flushing of the new shoots takes place, and because of this its death due to late frost may occur when there is no external sign of frost damage. In many cases after the severe frost in 1927 this was what happened with the result that it was not realised that plantations had in any way been injured until the middle

of the summer. Then it was seen that the trees were of a bad colour and that the bark of the main stem was being ruptured over the frosted parts. If trees injured in this way are examined it can be told that frost is the cause of the damage by the frost ring which will have developed in all parts where the cambium has not been killed. It will be seen on splitting a stem down that the frost ring was formed at the time the cambium was killed and that the death of the cambium and its abnormal growth are due to the same cause.

The Die-back of Leading Shoots.

This is a common phenomenon in conifer plantations, and especially in Douglas fir, Sitka spruce and Norway spruce. It is often caused by frost and this can be determined by an examination of the wood, when the typical abnormal growth produced by a frost injured cambium can be seen. Very often the whole of the cambium on the part that has died back is not killed. For example, in a Sitka spruce which had died back for about two and a half feet, the cambium was killed and girdled in the two-year shoot, but only injured sufficiently to cause the formation of a frost ring in the one-year shoot, which before death took place had time to develop a few rows of normal tracheids after the frost ring had been formed. Die-back of the leading shoots does not of necessity or usually occur simultaneously with the girdling of the main stem near the ground. The latter type of injury is perhaps most serious where the canopy is yet to be formed whereas die-back of shoots can be quite common and serious after this has happened.

The Formation of Cankers.

Wherever the two types of injury to the cambium already described take place, the formation of frost cankers is likely to occur. Frost cankers are most serious when on the main stem. A seriously cankered stem may fail to recover even though it is not girdled at any point. While frost cankers are to be found on broad-leaved trees or shrubs, e.g., apple, ash or beech, they are most common

and serious on conifers, and all species grown in Britain are liable to develop them. Since April, 1927, they have been observed on Douglas fir, Sitka spruce, European larch, Corsican pine and Scots pine. This type of injury has been most widespread and serious on the first two species which seem to be much the most frost sensitive of the forest trees of economic importance in Britain. The anatomy of a cankered stem is essentially the same as that of a girdled stem. Indeed, girdling of a stem, by frost is merely a serious type of canker injury. As in the case of other types of frost injury to the cambium, frost canker in conifers can be distinguished by the presence of a frost ring which develops at the same time as the canker. In European larch the frost ring may be very slight and sometimes it may be very difficult to decide whether frost or fungus was in the first place the cause of the canker. With the exception of certain cases on European larch, in which it was difficult to decide what was the cause of the injury, all cankers observed so far have dated from the severe late frost at the end of April, 1927. Whether cankers of this type heal up or continue to enlarge depends, of course, on the weather conditions in the ensuing years. If severe late frosts occur in these also, then there is every likelihood of the cankers enlarging. Usually, however, it may be said that no such enlargement takes place.

The Conditions Favouring Frost Injury to the Cambium.

The conditions which favour frost injury in general also favour this particular type of injury. Wherever cold air is likely to collect, as in frost hollows, or flat areas, where it cannot drain away, the cambium is liable to be injured. These conditions are so well known that there is no need to go further into them. The girdling of the main stem near to the ground takes place, however, only as a result of very severe cold such as often does not arise merely from the failure of cold air to drain away from any particular area. It has so far occurred to a serious extent only in localities where the surface vegetation is dominantly grass. This association between grass and severe frost damage is due to the very low temperatures that may occur

over any grass covered ground. If the minimum grass temperatures and minimum shade temperatures at any particular place are examined it will be found that the former is always somewhat the lower. This is, of course, well known, but it is not always realised how very much lower it may be. Thus, at the Radcliffe Observatory, Oxford, on April 30th, 1927, the minimum shade temperature was 28 deg. F., and the minimum grass temperature 18.5 deg. F. or 9.5 deg. F. lower. The temperature is lowest at the tips of the grass blades over which a zone of cold air lies. The influence of this is felt for some height up, as is shown by the figures taken by Homén in Finland (3) and set out in the following table. For comparison, temperatures taken in a neighbouring pine forest are given :—

	Open field.			Pine forest.	
Height over soil ...	0.	0.9	2.0	0	1.5 metres
28th July, 1 a.m. ...	–2.5	1.5	4.0	7.3	7.0°C.
27th Aug., 12.15 a.m.	–5.5	2.0	0.7	4.8	4.8
11th & 12th Sept., 5.30 a.m.	–4.8	–1.4	0.0	4.3	4.8

The ill-effect of grass in heightening the injury caused by frost is noted by Fabricius (2) in Denmark and Staudacher (6) in Germany. There is no doubt that a dominant surface vegetation of grass will sometimes make serious loss possible in an area which would otherwise not suffer greatly from frost damage, and that in such areas it may be not only difficult but also expensive to raise crops of either Douglas fir or Sitka spruce unless adequate protection against frost can be given.

Injury to New Shoots and Leaves.

This type of frost injury is so well-known that there is no need to enter into any general discussion of it; but a matter of interest may be mentioned which is also of importance in its prevention. It is a well-known fact that in certain species a number of races or types exist which have

different characteristics. One of the characteristics by which such types may differ is in the date of flushing of the new shoots. Thus it has been noted on a number of occasions that early and late flushing types exist in broad-leaved species such as pedunculate oak, beech or horse chestnut. Indeed it must be a matter of common observation that there is often a great difference in the date at which the new leaves appear on different trees of the same species. The importance of this in reference to frost is that the early flushing types tend to be much more often injured by late frost than the late flushing types. Thus, in a recent paper in this journal (7) the frosting of the flower of an early flushing pedunculate oak is noted.

While the existence of types differing in date of flushing is not without its importance in broad-leaved species, it is of much greater economic importance in connection with conifers. Much attention has recently been given in Germany to early and late flushing types of Norway spruce. The early flushing spruce is the most common and usually the most profitable type to grow. The late flushing type is to be found chiefly at high elevations and in frost areas. The reason for this is that owing to its inherent characteristic of flushing late in the year it is able to thrive where the earlier flushing type would be cut back and killed. Its value in frost areas is plain from figures given by Münch (4). In one locality he found that 90-92 per cent. of the early type had lost their leading shoot owing to frost while only 12 per cent. of the late type had so suffered.

The other conifer in which early and late flushing types have appeared is the green Douglas fir. If specimens of the coastal and interior dry belt types of this tree are taken it will be found that the latter type always tends to suffer much the more severely from late frost and that this is due to its flushing somewhat earlier than the other. Thus during the late frost at the end of April, 1927, in Kennington Nursery, Oxford, 19 per cent of the coastal type had the new shoots cut back, while from 38 to 79 per cent. of interior dry belt type suffered in the same way. It is probable that both types are equally frost sensitive, the

relative immunity of the coastal type being due solely to the later date of flushing.

Injury to the Bark.

This is a type of frost damage which is not usually considered. Nevertheless it may, upon occasion, be of some importance. It has come into notice recently on Douglas fir stems, in which frost rings are to be found. It results in the production of an abnormally rough and furrowed bark. What actually happens is that at the time when the cambium is injured, with the result that a frost ring is formed, certain injury also takes place in the living bark with the result that a cork layer is formed running deep within the tissues to cut off the part affected. The cork layer may cut off the cortical tissues only or may run through the phloem, depending of course on how deeply the bark has been seriously injured. The parts cut off in this way split as the tree grows and so produce the rough appearance characteristic of this type of injury. In the specimens examined so far the base of the main stem has been the most seriously affected and there is no doubt that frosting of the bark tends to occur under the same conditions and owing to the same causes as the girdling or cankering of the base of the main stem.

In Sitka spruce a slighter form of bark injury is seen in the development of abnormally large resin cavities. These often burst with the result that a flow of resin occurs. Sometimes these cavities occur at the edge of frost cankers, but they may also be found where no fatal injury to the cambium has occurred.

European larch may also suffer from bark injury. Occasionally it may be seen that fructifications of *Dasyscypha calycina* occur on living stems and on apparently uninjured areas of bark within which no dead dwarf shoot or branch occurs. An examination will show that these areas are cut off from the remainder of the tissues by a cork layer and that it is within this isolated dead portion that the fungus has developed. Such areas of bark as this are to be found where a frost ring has formed in the wood as in the case of the Douglas fir.

Injury by Autumn or Early Frost.

While injury to the cambium or bark may doubtless occur owing to severe early frost, the chief type of damage suffered is the cutting back of unripened shoots. This happens on both broad-leaved trees and conifers. Thus oak, especially after defoliation or mildew attack may be seriously affected. Also conifers such as the green Douglas fir, which often forms lammas shoots, may be cut back. Thus in a German nursery (1) it was found that while the blue Douglas fir suffered most from frost in the spring owing to its flushing early, the green fir suffered most in the autumn and a severe early frost might spoil over half the crop. The conditions there are presumably more severe than those usually experienced here in autumn and it is probable that the climate being more of a continental type than that of Britain, the blue Douglas fir is really more suited to it.

The Prevention of Frost Damage.

In nurseries this can be done by giving overhead cover to sensitive species, but out in the forest it may be more difficult if not impossible to take effective measures. In the first place it must be recognised that certain of the conifers favoured to-day are quite definitely frost sensitive. This is already sufficiently realised to prevent Douglas fir or Sitka spruce being set in bad frost hollows. What has often still to be understood is that there are areas on which very low temperatures are likely to occur immediately over the ground, especially when this is densely covered with grass. These areas may be, apart from this, admirably suited to the growing of frost sensitive species such as those named above, and providing no severe late frosts occur, plantations may thrive exceedingly well. However, should there be but one season when such a severe frost does occur, very severe damage will be done no matter how well grown the trees are. After the canopy has closed and weeds are suppressed, frost injury under these conditions is unlikely to occur as the crowns of the trees give protection to the main stem. Such injury as does occur then will be confined to the exposed crowns of the

trees. It is possible that sometimes in such localities it will pay to plant under an advance crop of a hardy species such as birch. This is done in frost areas with Sitka spruce in Denmark (2). Bad drainage may also favour frost damage and should always be attended to wherever a frost sensitive species is to be planted. In bad frost hollows it is difficult or impossible to prevent frost damage to sensitive species. Their planting must then be abandoned and a really frost hardy species chosen. Only thus is the profitable utilisation of such localities possible.

The Relation between Frost Damage and Fungal Attack.

This is two-fold. In the first place, as with trees affected with mildew, the fungus may so delay the ripening of the shoots as to make them susceptible to early frost. In the second and more important, shoots or other parts killed by frost may act as suitable centres of colonisation for parasitic fungi. Thus Douglas fir and Sitka spruce that have been cut back or cankered by frost commonly show either *Phomopsis pseudotsugæ* Wilson, or *Myxosporium abietinum* Rostrup in the killed parts. So far it has not been observed that these fungi act in any other way than as secondary parasites attacking the weakened trees and using the frosted parts as infection centres. In no trees except those very badly injured were they acting as virulent parasites. This type of relationship between frost and fungus has long been known, but is easily overlooked with the result that a weak parasite may be regarded as a virulent one.

Another matter that is still receiving attention is the possibility that frost is a precursor of attack by the larch canker fungus. In some cases where frost cankers have definitely occurred on European larch, *Dasyscypha calycina* has colonised the dead tissue and fructified on it. The occurrence of the fructifications of this fungus on frost injured bark has already been mentioned. Exactly how important frost is as a forerunner of *D. calycina* has yet to be determined. Evidence is accumulating, however, that where a very severe die-back of larch takes place and appears to be due to canker and especially small branch cankers, frost acts as one of the causes making the disease possible. Other factors, such as the quality and type of

soil and silvicultural treatment also enter in and need to be considered together with it.

Conclusion.

It has been possible in this short survey to touch only some of the more salient points regarding frost damage and especially such as have come into prominence since the spring of 1927, when so many trees and especially conifers suffered in one way or another from frost damage. There has always been a tendency to take sides for or against frost damage as a serious cause of loss in forestry. For this reason frost has often been overlooked or overvalued as a cause of disease. It should be recognised that frost damage is not always easy to identify. Thus when the main stem of a conifer is injured by late frost, no sign of serious damage may appear until well into the following summer. If injury to the leaves occurs it may be equally difficult in some cases to decide whether frost has caused their death unless a close observation of the trees has shown that this is so. Nevertheless it is important, not only that frost shall not be blamed for damage it does not cause, but also that it shall be recognised upon the right occasions as being the primary cause, for only thus can the importance of the more or less parasitic fungi that follow it be truly estimated. It is also well to remember that frost injured trees provide a breeding ground not only for fungi, but also for insects. The causes of disease thus become added to one another and complicate the problem of prevention and control. It must, however, be recognised that where frost is the primary cause of disease, it is only by preventing further frost damage that future loss is to be avoided no matter how necessary it may be, for the time being, to destroy fungal or insect pests present.

Frost, and especially late frost, is so important an adverse factor to the growth of trees, and especially of the more important exotic conifers, that a close study by a forester of the area within his charge with a view to determining frost damage is likely to occur is well worth while. Only thus can mistakes in planting be avoided and the occurrence prevented of the considerable losses that take place from time to time owing to frost.

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